DESY Ultimate Camera Check Script

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Ralitsa Mancheva

SU 'St. Kliment Ohridski', Bulgaria

Supervisor
Anna Oppelt

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Abstract

Radiation leads to damage in the PITZ cameras. This project aims to develop a script that assesses decision for camera replacement and helps to study the parameters of the noises that occur.

Contents

1   Introduction and motivation

The Photo Injector Test Facility (PITZ) at DESY, Zeuthen serves as a research center for testing and optimizing sources of high brightness electron beams for Free Electron Lasers such as XFEL [4] and FLASH [3] at DESY Hamburg and future linear colliders (see Figure 1). The main purpose of PITZ is to produce intense electron beams with very small transverse emittance and reasonably small longitudinal emittance, which are required in order to meet the high-gain conditions of FEL operation [1].
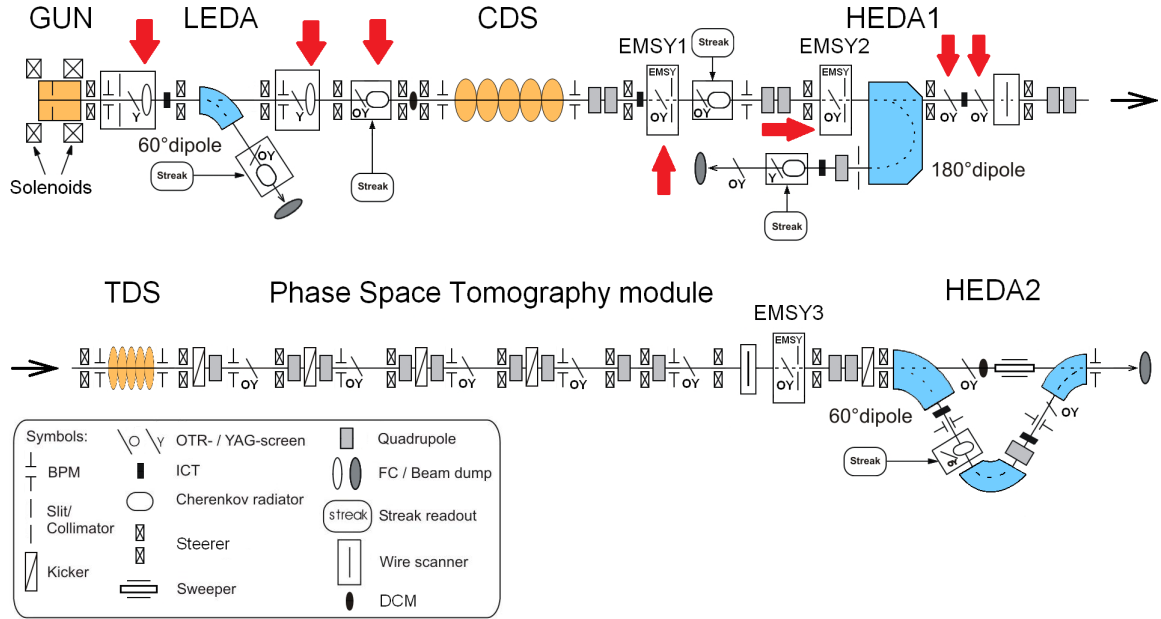

Figure 1: PITZ facility layout(Red arrows indicate screen stations for the cameras used in the project)

In order to capture the beam properties, most of the measurement techniques use screen stations with CCD cameras. The cameras used for electron beam diagnostics are AVT Prosilica GC 1350 [2]. This camera model has wide applications including industrial inspection, machine vision, ophthalmology, aeronautical and aerospace engineering, public security, surveillance and traffic imaging. Since the cameras are used at accelerators, where the radiation levels increase during operation, it is usual for the cameras to get damaged over time by radiation and this effect results in a certain frequency of growth of corrupted data. Subsequently, the cameras at PITZ are periodically replaced. The aim of this project is to help determine when it is time to replace a certain camera and to give information on the frequency and characteristics of the bad frames (frames with image distortion) and what is the threshold of parameters over which the frame is considered bad.

2   Camera parameters

The main camera parameters that are taken into consideration while capturing the beam are gain and exposure.

Gain is a digital camera setting that controls the amplification of the signal from the

camera sensor. It should be noted that this amplifies the whole signal, including any associated background noise. In this camera model the gain can be changed manually with values ranging from 0 to 25dB.

The exposure time (also referred to as shutter speed) of a camera determines the time of data gathering. The Prosilica GC 1350 cameras have a manual exposure control with values from 8 µs to 116.8 second. At PITZ, the exposure can range from 10 to 90 000 µs, because it is simply not needed for higher values.

The Prosilica GC 1350 has a 1360x1024 resolution and pixel size of 4.65 µm × 4.65 µm. Often the cameras are not used in their full resolution: they have 2x2 binning, which means that 4 pixels are combined into 1 in order to increase the signal intensity (see Figure 2).
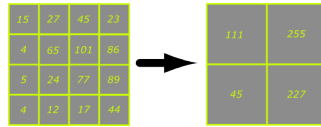

Figure 2: An example of 2x2 binning of cells

Like all electronics, cameras are easily damaged by radiation. Since the accelerator operation produces different types of radiation, the cameras are protected by lead bricks, which stop most of the radiation (see Figure 3). Although the effect is significantly reduced, some radiation still reaches the cameras. Over time, this leads to their damaging that requires their replacement.

(a) Prosilica GC 1350
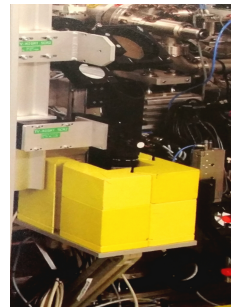
(b) Lead block barrier

Figure 3: Prosilica GC 1350

There are two types of corrupted frames that have been found in the data set gathered from the cameras: scanline noise in the form of thin stripes of fixed spatial frequency (at around 27 lines/mm) and an increased luminosity on one of the edges of a frame which for simplicity will be called 'border flashing' from this point on (see Figure 4).

Figure 4: Good frame (top), Scanline noise (middle), Edge flashing (bottom)
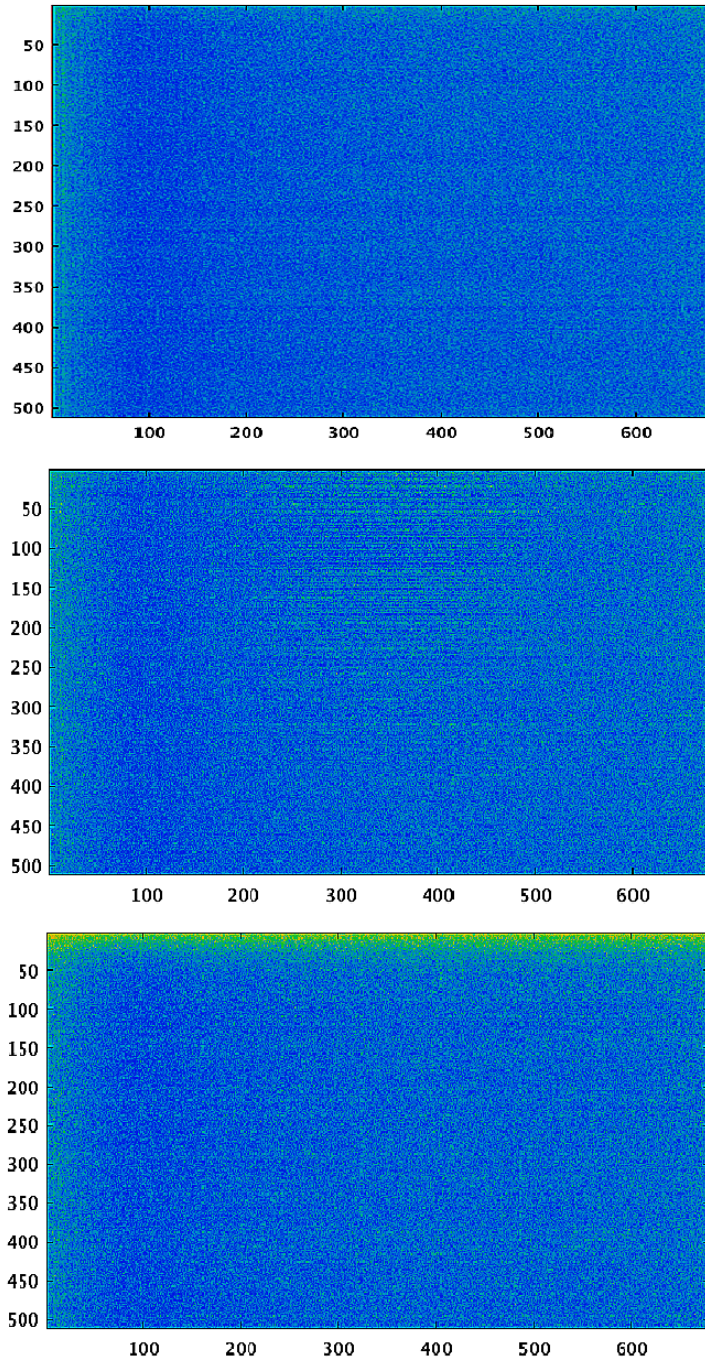
In order to isolate the background noise the FFT (fast Fourier transform) algorithm is used. The Fourier transform deconstructs a time domain representation of a signal into the frequency components. The frequency domain shows the signal present at varying frequencies. It is a different way to look at the same signal. The FFT operates by decomposing an N point time domain signal into N time domain signals each composed of a single point. The next step is to calculate the N frequency spectra corresponding to these N time domain signals. Lastly, the N spectra are synthesized into a single frequency spectrum. The FFT is an optimized implementation of a discrete Fourier transform (DFT) that takes less computation to perform but essentially just deconstructs a signal.

The signal that comes from the cameras is in the form of impulses that can be represented by a rectangular function (see Figure 5). The FFT of a rectangular function is the sinc function defined as

$$sinc(f) = A.sin(\pi f)/f$$
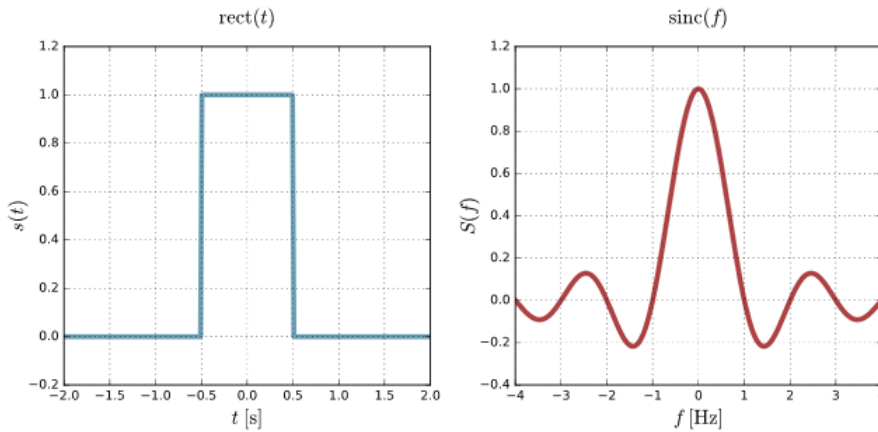
Figure 5: Rectangular pulse and its Fourier transform

If the FFT of a real data set is plotted, there are clearly visible peaks. To determine whether they are corrupted frames due to background radiation, we set a threshold determined by the decay envelope

$$(1/\lambda)$$

of the sinc function of an imaginary data set, which can be considered as 'good data'. The imaginary data that is constructed has the same dimensions as the real data set- pixel resolution, binning and is also in a rectangular pulse form. The multiple lines on Figure 6 represent the decay envelope at different magnitudes.
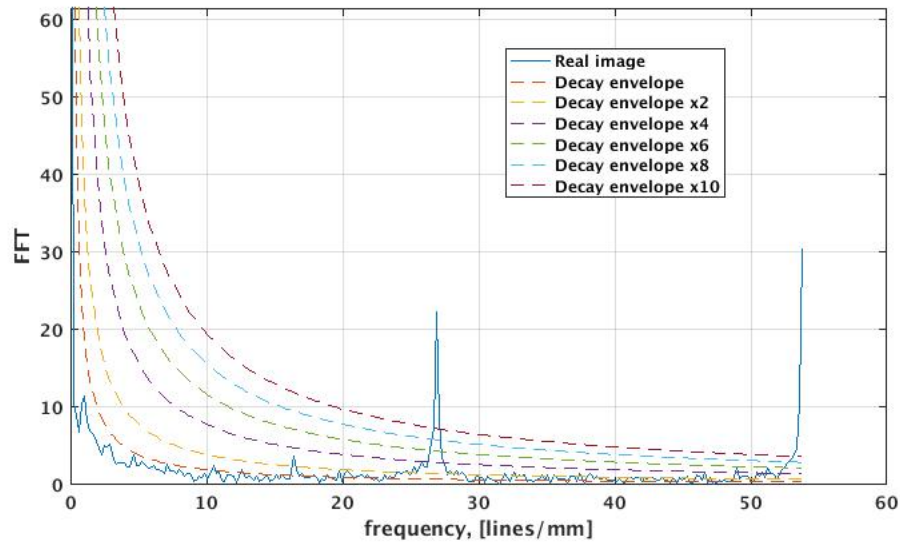
Figure 6: FFT of real data and envelope of imaginary data

The edge flashing is removed by taking the standard deviation of each frame and setting a threshold at 3 times the standard deviation plus the mode of the data (most frequent number in a data set). Whatever is left over that threshold is a bad frame with edge flashing.

3   DUCCS

The DESY Ultimate Camera Check Script is made using Matlab. The structure of the code follows these steps which are repeated in a loop for all six cameras:

Switching on a camera

Disconnecting all cameras from all frame grabbers

Connecting a camera to a certain frame grabber

Changing camera settings (gain and exposure)

Saving 1000 images from camera

Switching camera off

Averaging the intensity of each frame and plotting it

Calculating the standard deviation of each frame and plotting it

Calculating the spatial frequency for each frame by taking the FFT

Calculating the threshold for the scan line noise and removing all frames over the threshold

Calculating the threshold for the edge flashing using the standard deviation and removing all frames over the threshold

Producing a table with error rate statistics

4   Experimental results of a test run

In this section the results for the six cameras with different settings are presented. The 'Time' column can have values 1 and 0 representing whether the camera has warmed up properly or if it was just turned on. 'SL noise' is the number of noisy frames due to scanline noise and 'Edge flashes' is the number of noisy frames with border flashing. The 'Error rate' column shows the sum of the number of noisy frames with scanline noise and border flashing over the number of frames taken. That seems to give an accurate representation of the overall error rate, because so far no frames with both types of noise have been found.

Gain	Exposure	Number of frames	Time	SL noise	Edge flashes	Error rate
0	20	1000	1	9	0	0.009
0	50000	1000	1	96	0	0.096
0	90000	1000	1	0	1	0.001
5	20	1000	1	71	0	0.071
15	20	1000	1	0	25	0.025
25	20	1000	1	0	0	0

Table 1: Low.Scr2 camera

Gain	Exposure	Number of frames	Time	SL noise	Edge flashes	Error rate
0	20	1000	1	21	86	0.107
0	50000	1000	1	14	58	0.072
0	90000	1000	1	0	0	0
5	20	1000	1	334	0	0.334
15	20	1000	1	23	0	0.023
25	20	1000	1	14	1	0.015

Table 2: Low.Scr3 camera

Gain	Exposure	Number of frames	Time	SL noise	Edge flashes	Error rate
0	20	1000	1	17	84	0.101
0	50000	1000	1	34	0	0.034
0	90000	1000	1	0	0	0
5	20	1000	1	61	39	0.1
15	20	1000	1	7	50	0.057
25	20	1000	1	33	50	0.083

Table 3: High1.Scr1 camera

Gain	Exposure	Number of frames	Time	SL noise	Edge flashes	Error rate
0	20	1000	1	5	30	0.035
0	50000	1000	1	0	1	0.001
0	90000	1000	1	0	0	0
5	20	1000	1	33	29	0.062
15	20	1000	1	18	73	0.091
25	20	1000	1	1	64	0.065

Table 4: High1.Scr3 camera

Gain	Exposure	Number of frames	Time	SL noise	Edge flashes	Error rate
0	20	1000	1	10	63	0.073
0	50000	1000	1	0	0	0
0	90000	1000	1	0	109	0.109
5	20	1000	1	39	93	0.072
15	20	1000	1	22	89	0.132
25	20	1000	1	18	100	0.118

Table 5: High1.Scr4 camera

Gain	Exposure	Number of frames	Time	SL noise	Edge flashes	Error rate
0	20	1000	1	7	58	0.065
0	50000	1000	1	0	0	0
0	90000	1000	1	0	0	0
5	20	1000	1	42	70	0.112
15	20	1000	1	11	36	0.047
25	20	1000	1	16	26	0.042

Table 6: High1.Scr5 camera

Camera	Date of last replacement
Low.Scr2	December 2015
Low.Scr3	December 2016
High1.Scr1	November 2015
High1.Scr3	March 2017
High1.Scr4	January 2012
High1.Scr5	November 2015

Table 7: Date of last replacement for each camera

These results are a test run that shows that the program is ready to gather data and do an analysis of it. The results do not present a clear outcome, because there are more parameters that should be taken into consideration. For instance, the radiation levels vary along the beamline, which skews the results. From Table 2 and Table 3 for gain value 0 and exposure value 20 it seems that the error rate for cameras Low.Scr3 and High1.Scr1 are higher than the other cameras (with the same settings). A possible explanation for this is that those two cameras are located near the CDS Booster (see Figure 1) which causes high dark current that may be influencing those particular cameras. Another point to be made is that for different camera settings the results vary. For high exposure values (50000 and 90000) the results do not seem to be fully accurate, but are presented here to show the limitations of the current version of the script. Another outcome of these results is that the frequency of noisy frames does not seem to directly correlate with the age of the cameras (see Table 7).

5   Conclusion

The DUCCS tool is a useful way to keep track of the health of the cameras at PITZ and can be improved and generalized for other types of cameras in order to be used with different hardware (at other facilities as well). It is interesting to see the parameters of the corrupted data and to asses the overall health of the cameras. In general, the tool gives a lot of additional information to its intended purpose.

The tool is ready for data gathering and analysis and can already be used. First results are obtained, however a more detailed study of the camera behavior is needed in order to give a more clear outcome from the results. More data has to be gathered and a deeper analysis should be made with more parameters to be taken into consideration like the

radiation level variety in the beamline, the range of possible settings for the cameras, the date of installation etc. An analysis of the background slope is also a parameter that needs further investigations. Ultimately the tool should be integrated into the control system. These next steps for the DUCCS tool will be continued by the PITZ group.

6 Acknowledgements

References

[1] P. Schmuser, M. Dohlus, and J. Rossbach, *Ultraviolet and soft x-ray free-electron lasers: Introduction to physical principes, experimental results, technological challenges*, vol. 229 of *Springer Tracts in Modern Physics.* Springer, 2009.

[2] Documentation on AVT Prosilica GC 1350: https://www.alliedvision.com/en/support/technical-documentation/prosilica-gc-documentation.html .

[3] Homepage of the FLASH Project: http://flash.desy.de/.

[4] Homepage of the European XFEL project: http://xfel.desy.de/ .